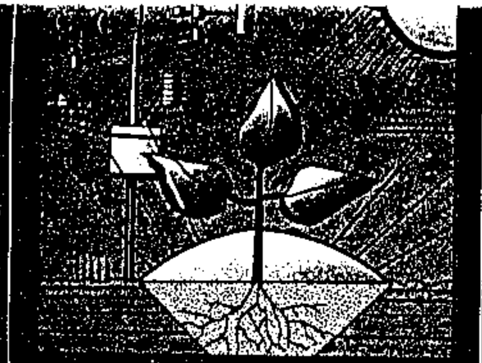

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Effects of Instrument Shelters on Air Temperature and Humidity Measurements

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ABSTRACT

Automated agricultural weather stations often use naturally aspirated radiation shields for the air temperature and relative humidity sensors. A study was undertaken to compare a standard cotton belt shelter (CBS) widely used in the U.S. for manual weather observations with a naturally aspirated (NAT) shield and a forced aspirated (ASP) shield with the same type temperature and relative humidity sensor. Both the ASP and NAT shields had temperatures about 1.8 to 2.1°C higher than observed in the CBS shield, but both were linearly correlated to CBS measurements with a slope near unity. Relative humidity (RH) indicated only about a 1.5% RH difference between the shields. The NAT and ASP shields affected temperatures enough to bias maximum daily air temperatures by 8%(mean difference was 1.9°C), computed reference evapotranspiration by 11% (mean difference was 0.6 mm d^{-1}), or growing degree days (GDD) by 1°C-d. These differences are large enough to warrant a thorough study of radiation shelters used in automated agricultural weather stations. These differences could significantly affect reliability of such data for irrigation scheduling or crop growth modeling purposes.

Keywords: Automated weather network, Climate, Electronic sensors, Growing degree days

INTRODUCTION

Weather parameters affect evapotranspiration (ET) and many other local environmental factors that influence crop growth and yield. Air temperature and relative humidity are primary weather parameters that are routinely measured along with solar radiation, wind speed and direction, barometric pressure, precipitation, and soil temperature at many weather stations. Historically in the U.S., air temperature has been measured by the National Weather Service (NOAA-NWS) in cotton belt shelters (CBS) located about 1.5 m above the ground using mercury in glass and alcohol in glass thermometers to determine daily maximum and minimum temperatures, and relative humidity (RH) was often observed periodically (usually at 8:00 am or 4:00 pm local time) with sling psychrometers or continuously monitored with hair hygrometers. During the past 15 years, automated agricultural weather stations have become widely used (see Hubbard et al., 1983; Snyder, 1983; Howell et al., 1984; Ley and Muzzy, 1992; Brock et al., 1994 for examples). However, these stations typically use unaspirated instrument shelters and electronic instruments with different time responses from the historical NWS data. Few comparisons have been made between traditional NWS methods and newer electronic, automated weather stations. Fuchs and Tanner (1965) examined various sensor shield coatings on solar and thermal errors. Huband et al. (1984) reported maximum temperatures were greater in a Dicot shelter (unaspirated) than a Stevenson shelter (widely used in Europe and outside the U.S.) by up to 1°C while minimum temperatures were up to 1.5°C lower in the Dicot shelter on clear, still

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nights. Ventilation from wind is known to affect sensor performance in unaspirated shelters. For example, the specifications on the Gill multi-plate shield (R.M. Young model 41002), which is widely used in automated weather stations, indicates temperature errors of up to 0.7°C from radiation heating when wind speeds are less than 2 m s^{-1} (up to 1.5°C when wind speed < 1 m s^{-1}) with solar radiation intensities of 1.08 kW m^{-2}, which can routinely occur in many locations throughout the U.S. and world. Brock et al. (1995) examined the heating errors for the Gill multi-plate shield and observed that sensor heating directly or indirectly from absorbed radiation similar to reports by Gill (see R.M. Young information) and indicated that aspiration of the Gill shield might improve its performance.

Systematic air temperature errors or bias may affect the usefulness of data collected by automated weather stations for estimating parameters such as ET or growing degree days (GDD) computed using weather data. In addition, weathers station siting (or fetch) can introduce equally important errors (Brown and Ley, 1993). Allen and Pruitt (1986) proposed an empirical scheme to adjust weather station data based on site characteristics, but their method has not been widely evaluated.

The purpose of this paper is to report and summarize air temperature and relative humidity differences measured using electronic sensors housed in an unaspirated standard NWS Cotton Belt Shelter, an unaspirated Gill multi-plate shield, and an aspirated shield. The unaspirated Gill shield is similar to that used in many automated agricultural weather stations around the world.

METHODS AND MATERIALS

The study was conducted at the USDA-ARS Laboratory at Bushland, TX (35° 11' N lat.; 102° 06' W long.; 1,170 m elev. above mean seal level). The various radiation shields used in this study are part of the instrumentation for an ET weather station located over an irrigated grass surface (Dusek et al, 1987). The station includes instruments for measuring solar radiation and its components, temperature, relative humidity, dew point temperature, wind speed and direction, rainfall, soil heat flux, soil temperature, and a grass reference ET lysimeter. (See Dusek and Howell (1993) and Howell et al. (1995) for additional details.)

The study used three types of radiation shields or shelters (Fig. 1). A standard NWS (NOAA-NWS) cotton belt shelter was the check radiation shelter (standard) and two mast mounted radiation shields — a Gill multi-plate (R.M. Young, model 40012), which was naturally aspirated (NAT), and an aspirated (ASP) shield (Eastern Scientific Products, model HVAF25). The CBS is a wooden louvered shelter mounted on galvanized steel angle-iron legs so that its bottom is about 1.5 m above ground. The aspirated shield was powered by a 115 VAC fan that pulled air across the sensor at a rated velocity of 5-6 m s^{-1}. Both the NAT and ASP shields and sensors were mounted on a standard three-sided radio tower/mast about 4 m from the CBS. The CBS sensor was mounted on the instrument board in the CBS at about 1.7 to 1.8 m above the ground. The

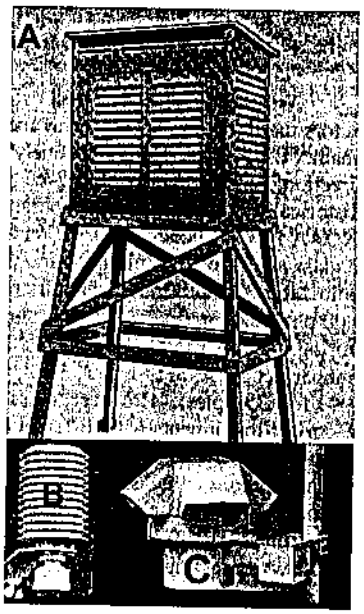

Figure 1. Illustrations of the Temperature/Radiation Shelters with A (top) Depicting the Cotton Belt Shelter; B (bottom left) Depicting the Multi-Plate Gill Shield; and C (bottom right) Depicting the Aspirated Rotronic Shelter.

NAT sensor was mounted so that the electronic probe was 2.0 m above ground, and the ASP shield was mounted so that the air inlet was 2.0 m above ground. The deployment of the NAT shield and sensor simulated common automated agricultural weather stations. The CBS was painted white (both inside and out), and the NAT and ASP shields were both white. Neither the NAT or ASP shields were insulated in any way.

The sensors mounted in the NAT and ASP shields were MP-100 Rotronic temperature and RH probes which required 12 VDC excitation (supplied by the data logger), and the sensor in the CBS was a Rotronic HT-225 model temperature and RH sensor using 115 VAC power. The rated accuracy of the HT-225 temperature probe was ± 0.5°C. The accuracy for RH was listed as ± 1.5% from 0-35% RH, and ± 2% from 35-100% RH. The stated limits of the MP-100 temperature were the same as the HT-225, while the RH sensor was ± 2% from 0-100% RH. Campbell Scientific CR-7X and CR-21X data loggers were used during the study. Data sampling frequency was 0.17 Hz (6 s), and signals were averaged for 15 min outputs.

Sensor Comparisons

Two Rotronic MP-100 sensors were placed in the CBS and compared directly with the other electronic sensor (Rotronic HT-225) for 2-3 days before they were moved to either the ASP or NAT shields. The other two sensors, already in the NAT and ASP shields as a part of the overall instrumentation of the station, were rotated from their locations to the CBS shelter, and then they were directly compared with the HT-225 electronic sensor.

Full instrumentation was implemented and data collection of all sensors began in early August 1995 and continued for an 18-day period while sensor rotations were being implemented. A second data set was obtained in early October. This second set of measurements was collected mainly to check for similar trends to the August period, and no sensor rotations were made in October.

Application Comparisons

Reference grass evapotranspiration (ET_o) (Allen et al., 1994) and growing degree days (GDD) for several crops were calculated from the air temperatures measured in the various shields. These data, as well as maximum, minimum, and daily temperature and relative humidity averages, were compared by linear regression for both hourly and daily periods and were compared with measured parameters and computed values (ET_o and GDD) using the air temperature and relative humidity measurements in the standard CBS shelter.

RESULTS

When the different MP-100 sensors were compared with the HT-225 electronic temperature and RH probe, it was evident they were all within the temperature specifications and agreed closely when in the confines of the standard CBS. This confirmed that the sensors and data loggers were performing similarly. A difference in RH of about 4.5% RH was experienced for two of the MP-100 sensors and -3.8% RH for a third. One RH sensor (the original in the ASP shield) was totally out of range and was omitted from these data.

When the MP-100 sensors were placed in the NAT and ASP shields, an immediate increase in temperature (Fig. 2) was noted. The increase was consistent and equal in both shields and measured by all four sensors. Daily average wind speed ranged from 3 to 7 m s^{-1} during the data collection periods, but ventilation did not appear to affect the differences in temperature or RH. Solar radiation varied considerably during this period but peak loads over 900 W m^{-2} were common near solar noon. It was not totally unexpected that the natural shield, under conditions of low wind, would produce such results, but it was a surprise that the aspirated shield with the high volume of air movement over the sensor also produced similar results to the NAT shield.

Previous measurements with insulated, shielded psychrometers (Dusek and Howell, 1993) agreed well with temperature and RH measured in the standard CBS.

Using daily summaries, averages, maximums, and minimums of the data, a 2.1°C increase in temperatures was observed for the ASP shield and a slightly lower 1.8°C increase in the NAT shield. The 0.3°C difference could easily be an instrumentation error and is within the sensor error limits for temperatures. The differences were generally linear, except at lower temperatures, and averaged 8% above the measured data from the standard CBS (Fig. 3).

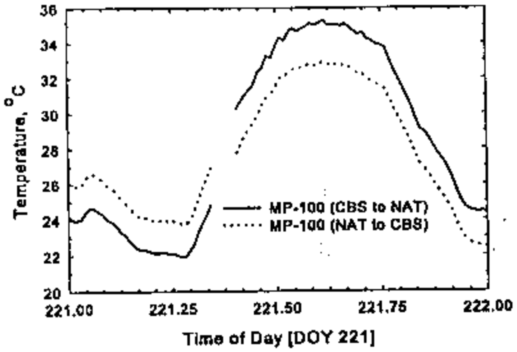

Figure 2. An Example of the Temperature Change When Two MP-100 Sensors Were Switched Between The Cotton Belt Shelter (CBS) and the Naturally Aspirated Shelter (NAT). The "Gap" in the Graph Was When the Sensors Were Exchanged.

Relative humidity was increased by 6% RH with the ASP shield and was about 0.75% RH less than the NAT shield. The 6% RH difference minus the 4.5% RH difference in the standard CBS between the MP-100's and the HT-225 electronic sensor indicates only a 1.5% RH increase in RH due to the shelters. This difference is less than the accuracy of the sensors and is, therefore, not considered a "significant" difference. The average differences were virtually the same for data in August and in October. Further measurements of RH, after re-calibration, are needed to substantiate whether differences measured between the standard CBS shelter and the ASP and NAT shelters are real. We don't fully understand why RH would be increased rather than decreased by the elevated air temperatures, but the measured differences were consistent.

The increase in maximum and minimum temperatures in the shields resulted in an average increase of 11% (mean difference over the range was 0.6 mm d^{-1}) in calculated reference ET (grass reference) (Fig. 4) on the average. Calculated GDD for soybean (Fig. 5) and corn (data not shown) produced an average increase of 1°C-d for the ASP and NAT shelters compared with the standard CBS. These GDD errors could become significant when summed over many days and might be expected to affect plant growth model performance.

Linear regressions between the standard CBS data and ASP and NAT data for hourly and daily summaries were similar to the average differences (Table 1). Offsets of 1.5°C and slopes very near unity were common for hourly temperatures with a coefficient of determination (r^2) near one. The slope for hourly RH was also very close to unity with an offset of 6% RH and 8% RH for the two sensors, which measured 4.5% RH

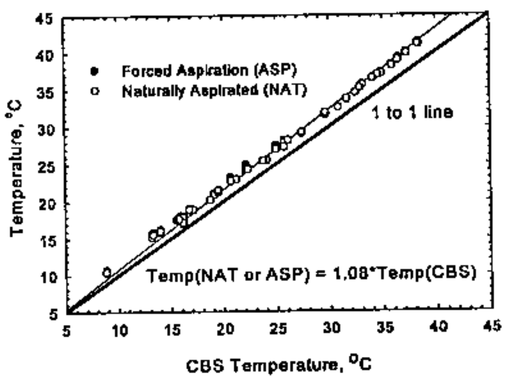

Figure 3. Increase in Maximum Daily Air Temperatures as Affected by Shelter Type.

Table 1. Average Maximum and Minimum Temperatures for All the Data; Averages for the August and October Data; Differences; and Linear Regression of Each Shield as Related to the CBS Standard. CBS - Cotton Belt Shelter; ASP - Forced Aspiration; NAT - Naturally Aspirated.

		Maximum Temperature			Minimum Temperature		
Parameter	Unit	CBS	ASP	NAT	CBS	ASP	NAT
Average (all data)	°C	24.55	26.70	26.57	6.75	8.89	8.48
Average (August)	°C	33.30	35.63	35.58	18.62	20.46	20.40
Average (October)	°C	18.93	20.96	20.77	-0.88	1.45	0.82
Difference (all data)	°C		2.15	2.01		2.14	1.73
Difference (August)	°C		2.34	2.28		1.84	1.78
Difference (October)	°C		2.02	1.84		2.34	1.70
Slope (all data)	°C °C^{-1}		1.024	1.028		0.977	1.005
Intercept (all data)	°C		1.566	1.314		2.293	1.701
r^2 (all data)	---		0.988	0.999		0.999	0.999

high in the standard CBS. The third MP-100 sensor retained a -3.5% RH offset in the ASP shield as well as in the standard CBS. Regression coefficients for RH were also close to unity.

CONCLUSIONS

Natural or forced aspiration instrument shelters with electronic temperature and RH sensors increased measured air temperature by nearly 2°C compared with a standard cotton belt shelter over a wide range of temperatures. However, aspiration did not seem to reduce heating loads appreciably for the ASP shield as suggested for an aspirated Gill shield by Brock et al. (1995). The possibility, though not wholly confirmed by this study, is that RH is also increased by as much as 2% RH or more. The reason for an increase in RH is not fully understood. The increases in temperature led to appreciable bias in both computed reference ET and GDDs. These differences are large enough to warrant a more detailed investigation of shelter and sensor errors used in automated agricultural weather stations.

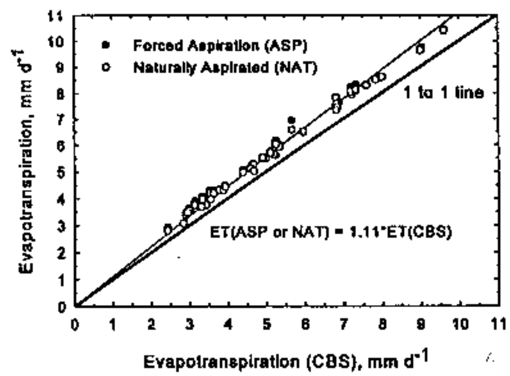

Figure 4. Increase in Computed Reference ET with Data From a Naturally Aspirated Shield (NAT) and an Aspirated Shield (ASP) Compared With Reference ET Computed With Data from the Cotton Belt Shelter (CBS).

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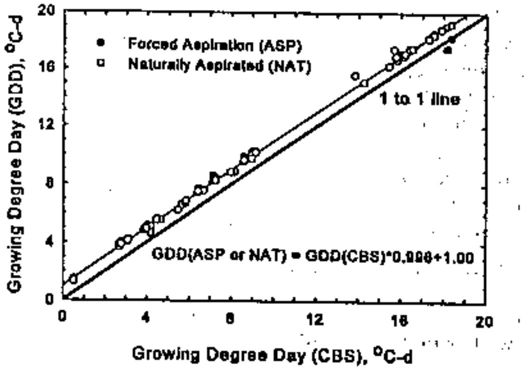

Figure 6. Increase in Computed Growing Degree Day (GDD) for Soybean Using Data From a Naturally Aspirated Shield (NAT) and an Aspirated Shield (ASP) Compared With GDD Computed With Data Measured in a Cotton Belt Shelter (CBS).

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